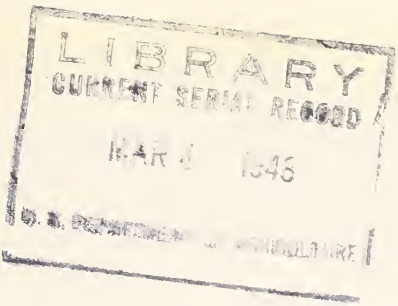

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Spacing Distances for Windbreak Trees on the Northern Great Plains

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CONTENTS

MORE INFORMATION NEEDED ON SPACING DISTANCES

Much of the settled area of the northern Great Plains is treeless, and tree planting is practiced chiefly for protection. So far, wood products such as posts, poles, and fuel have been of minor importance in the planted areas, but native stands yield considerable rough lumber, posts, and fuel.

Plains silviculture presents many difficult problems, some of which are quite different from the practices followed in forested areas. Plains trees are a farm crop, and the problems should be approached with an agricultural background and a broad-minded perspective free of preconceived ideas. Of the problems involved, that of spacing distances for windbreak trees arouses more controversy than any other.

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There is no serious disagreement in the recommendations of species suitable for the area. Those for spacing, however, often do not agree, and they cause considerable confusion to farmer-planters, many of whom have formed their own ideas on how far apart the trees should be planted. This circular discusses the growth and survival of trees spaced at various distances but grown under identical conditions for various periods. In general, green ash (*Fraxinus pennsylvanica* var. *lanceolata* (Borkh.) Sarg.) did better in mixed plantings than in pure ones spaced similarly. Spacings of 8 by 8 and 4 by 8 feet gave the best results in the respective tests. Thinning by removal of trees of other species in adjacent rows apparently did not benefit green ash. Siberian pea-tree (*Caragana arborescens* Lamb.) and Chinese elm (*Ulmus pumila* L.) were highly competitive with green ash when planted in rows 4 and 8 feet away. Close-spaced trees suffered less injury from drought than wide-spaced ones. Species like Chinese elm and Russian-olive (*Elaeagnus angustifolia* L.) suffered more injury in wide spacings than in close ones when the soil moisture was plentiful in the fall.

The results of the tests are summarized in more detail as follows: In a series of mixed plantings 27 years old, spaced 4 by 4, 4 by 8, 4 by 12, and 8 by 8 feet, green ash trees made the greatest over-all growth when spaced 8 by 8 feet. They made the poorest growth when they were spaced 4 by 4 feet; a high percentage of such trees were suppressed.

In pure plantings green ash made better growth and had higher survivals when spaced 4 by 8 feet than when spaced 4 by 4 feet.

In farm plantings variously spaced from 4 by 8 feet to 6 by 15 feet, the best over-all growth and highest survivals were made by trees spaced 4 by 8 feet. Growth and survival were found to have a tendency to decrease as the spacing distance increased.

Green ash made better growth and survived better in mixed plantings than in pure ones when spacings were the same.

In series of five- and six-row mixed combinations spaced 2 by 4, 4 by 4, and 4 by 8 feet, ponderosa pine (*Pinus ponderosa* Laws.) made the greatest over-all growth and had the highest survival in the widest spacings in each series. Loss of species in adjacent rows may have had some influence on growth in the closest distance.

The removal of species about 20 years after they were planted in rows adjacent to green ash had no beneficial effects on the growth of the green ash during the next 10 years. The average heights of the trees did not change appreciably. Unthinned trees, however, made fair to good progress during this period and generally maintained higher survivals.

Siberian pea-tree and Chinese elm were found to be highly competitive species when planted in rows 4 and 8 feet from green ash. The percentage of green ash suppressed was much lower, however, when Chinese elms were planted in rows 12 feet away.

The limited data available showed that green ash suffered more injury and made slower recovery from the severe droughts of 1934 and 1936 when the trees were spaced wide than when they were spaced close.

Species of indeterminate habit of growth, such as Chinese elm and Russian-olive, suffered more injury and greater losses from early freezes in wide spacings than in closer ones during falls when soil moisture was plentiful.

SPACING DISTANCES PREVIOUSLY USED OR RECOMMENDED

From observations and investigations made over a period of years in the northern Great Plains and somewhat similar areas, various spacings have been recommended in published literature. These fall in three main groups. Yeager (*20*),[1] Bates (*2*), and Ware (*17*) suggested distances varying from 4 to 8 feet apart for trees in the row and from 6 to 9 feet between rows. These distances permitted the branches to meet sooner than wider ones did, so that cultivation could be discontinued earlier. Ware (*17*) found that close spacing had given better results than wide spacing. He advised against more than 12 feet between rows.

Wilson and George (*19*), Isaac (*10*), Jensen and Harrington (*11*), Johnson and Cobb (*12*), Rockwell (*13*), Aune, Hurst, and Osenbrug (*1*), and Edmondson (*4*) recommended distances of 6 to 8 feet for trees in the row and of 8 to 24 feet between rows. Economy of cultivation by spacing the rows to fit the machinery found on most farms and to lessen the competition for moisture were the chief reasons advanced for the wider spacing.

As a result of studies of existing plantings Wilson and Cobb (*18*) found that a distance of 4 by 8 feet was too close; Scholz (*15*) found that trees having more than 40 square feet per tree suffered a higher mortality than those having less; Harrington and Morgan (*9*) decided that distances of 4 by 4 and 4 by 8 feet were too close; and George (*5*) concluded that spacing distance should be based on the growth habits of the species making up the planting.

In the Prairie Provinces of Canada, which have climatic conditions somewhat similar to those of the northern Great Plains, Ross (*14*) advised distances of 4 by 4 feet to reduce the number of years that cultivation would be necessary. He believed that when the crowns closed in a wider spacing there would be just as great a leaf development as when the trees were planted closer together. The same amount of moisture therefore was needed in both cases.

Vyssotsky (*16*) for many years had been interested in experiments in establishing forests in the Steppes of the Union of Soviet Socialist Republics. This is an area somewhat similar to the northern Great Plains in that it receives insufficient moisture for tree growth, has considerable snowfall, and has many alkaline soils. Vyssotsky found that strip plantations of sparsely planted trees as recommended by some silviculturists had not remained stable and given useful results. The trees branched out greatly and died out, and because of the absence of underbrush the soil became soddy and weeds developed excessively.

In a study of prairie shelterbelts in Minnesota, Deters and Schmitz (*3*) found that too close spacing had been an important factor in the deterioration of shelterbelts. These plantings had received a higher average annual rainfall than those on the northern Great Plains. Deters and Schmitz recommended an initial spacing of 4 by 8 feet in order to stimulate height growth and the later thinning of the plantings to give distances of 8 by 8 feet or greater. Bates (*2*) also made somewhat similar recommendations for the prairie-plains region.

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[1] Italic numbers in parentheses refer to Literature Cited, p. 27.

RESULTS DESIRED

The principal factor affecting growth and survival of trees in the northern Great Plains is rainfall. Average annual precipitation over much of the region is less than 15 inches. This amount is probably the minimum necessary for tree growth, and any year that falls below the average can be termed a "drought year." After the trees have made a few years of growth they leave at the end of the growing season little if any available moisture in the soil area occupied by the roots. The following year, therefore, they have to rely almost entirely on current moisture. The spacing distance that will maintain under average farm care the maximum growth and survival over the longest period and provide the dense growth necessary for adequate protection is the one to be used.

It is doubtful whether spacing distances should be based solely on widths of cultivation machinery. Trees in wide-spaced rows will branch considerably more than those in the close-spaced ones. If rows are 16 feet apart to accommodate 12-foot cultivators, the branching will be such that cultivators of this width could not be used after 4 or 5 years. It would therefore become necessary for the farmer to obtain a narrower cultivator or leave an open space about 10 feet wide to grow up to competitive weeds. In addition, farmers begin to neglect cultivation of their trees after the second or third year regardless of the spacing distance used. George (*6*) showed that only 50 percent of the 5-year-old plantings which needed cultivation were being cultivated. After 10, 20, and 25 years the percentage of plantings needing cultivation but not being cultivated was 48, 67, and 80 percent, respectively.

For outside rows the growth should be dense from the ground up. All writers agree that the trees should be spaced close together in these rows. Side branching is not so important in interior rows, but complete closure of the crowns at an early date to give 100-percent shade is highly essential. It makes little difference whether this is obtained by spacing the trees close together or wide apart, provided the length of time for them to develop crown closure is approximately equal and a high percentage of the trees are kept in a vigorous growing condition.

MATERIALS AND METHODS

The United States Department of Agriculture at the Northern Great Plains Field Station, Mandan, N. Dak., began the study of tree-planting problems on the northern Great Plains in 1915. Studies were made of experimental plantings at the Mandan station and of cooperative ones on a large number of farms in the northern Great Plains. In both station and farm plantings various spacing distances, which have yielded data indicating certain trends, have been used. A wider range of spacing distances in the earlier plantings, however, would have yielded more conclusive results.

Green ash (*Fraxinus pennsylvanica* var. *lanceolata*) was selected for study as representative of deciduous species. It gives much higher survivals than other species, is adapted to a wide range of soil and site types, is very drought-resistant, and is intolerant to shade and crowding in close spacing. In addition it is one of the few species on which diameters can be measured with a reasonable degree of accuracy. The

species was used in mixed and pure-stand plantings in 1918, in mixed plantings in 1915, 1916, and 1917, and in mixed farm plantings in 1916 through 1936.

Ponderosa pine (*Pinus ponderosa*) was selected as representative of the coniferous species because it is one of the most drought-resistant, is adapted to a wide range of soil and site types, and is extremely intolerant to shade and crowding in narrow spacing.

Other species and various spacing distances will be discussed briefly to emphasize certain points not brought out in connection with green ash and ponderosa pine. The following species were used in the studies:

American elm	*Ulmus americana* L.
Birch	*Betula* sp.
Black Hills spruce	*Picea glauca* var. *densata* Bailey
Boxelder	*Acer negundo* L.
Buffaloberry	*Shepherdia* sp.
Chinese elm	*Ulmus pumila*
Chokecherry	*Prunus* sp.
Jack pine	*Pinus banksiana* Lamb.
Poplar	*Populus* spp.
Russian-olive	*Elaeagnus angustifolia*
Scotch pine	*Pinus sylvestris* L.
Siberian pea-tree	*Caragana arborescens*
Tatarian maple	*Acer tataricum* L.
Willow	*Salix* spp.

CLIMATIC DATA

The average annual rainfall at the Mandan station for 1915–44, during which period records were taken, was 15.44 inches. The average for 1918–44, the period when the main tree tests under discussion were growing, was 15.32 inches. Of these 27 years 14 were above the average and 13 were below. The maximum received in any one of these years was 21.43 inches and the minimum was 6.43 inches.

Evaporation from a free-water surface during the growing season (April to September) averaged 33.8 inches for 1918–44.

Temperatures for 1918–44 reached extremes in both directions. The minimum during the period was −46° F., and the maximum was 115°. Subzero temperatures were recorded in January, February, March, November, and December. Temperatures of 100° or greater were recorded in June, July, August, and September.

Wind velocity averaged approximately 6 miles per hour for 1918–44.

GROWTH AND SURVIVAL OF DECIDUOUS PLANTINGS

Green Ash in Mixed Plantings

In the spring of 1918 green ash was planted in a series with various other species. The series consisted of four 10-row blocks of trees, 100 feet long, planted 4 by 4, 4 by 8, 4 by 12, and 8 by 8 feet. The rows were planted with the following species: Buffaloberry (row 1), willow, boxelder, green ash, boxelder, poplar, green ash, boxelder, willow, and Tatarian maple. The blocks were adjacent on similar sites

and soil types and received the cultivation necessary to control weeds. For several years prior to 1944 none of the plantings except that spaced 4 by 12 feet were cultivated; that needed yearly cultivation between rows. A small amount of leaf mulch was present in the plantings spaced 4 by 4 feet.

Height, crown spread, and diameter at breast height were measured and survival was determined when green ash had been planted for various periods (table 1). Data for the fourth year show the percentage of trees which became established, as losses were replaced the second and third years. Survival data for the fifth and later years were based on the stand established the fourth year, which in some instances may be less than the number of trees actually planted. Survivals of species in rows adjacent to the green ash were approximately the same for all spacing distances, and therefore they had little if any influence on the growth and survival of green ash.

TABLE 1.—*Effect of spacing distance on growth and survival of green ash set out in 1918 in mixed plantings*

Spacing distance	Planting of indicated age (years)						
	[1] 4	5	10	15	20	25	27
	Height						
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
4 by 4 feet	4. 0	6. 0	11. 0	11. 7	11. 9	13. 6	14. 6
4 by 8 feet	4. 3	5. 5	12. 2	15. 0	15. 9	17. 3	18. 6
4 by 12 feet	4. 2	6. 2	12. 0	16. 5	17. 7	19. 0	20. 1
8 by 8 feet	4. 5	6. 0	12. 5	16. 6	17. 4	18. 9	21. 2
	Diameter at breast height						
				Inches	*Inches*	*Inches*	*Inches*
4 by 4 feet	------	------	------	1. 1	1. 4	1. 6	1. 9
4 by 8 feet	------	------	------	1. 6	2. 2	2. 6	3. 1
4 by 12 feet	------	------	------	2. 1	2. 7	3. 1	3. 5
8 by 8 feet	------	------	------	2. 0	2. 7	3. 2	3. 7
	Crown spread						
							Feet
4 by 4 feet	------	------	------	------	------	------	4. 5
4 by 8 feet	------	------	------	------	------	------	7. 5
4 by 12 feet	------	------	------	------	------	------	8. 5
8 by 8 feet	------	------	------	------	------	------	8. 5
	Survival						
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
4 by 4 feet	92	100	100	100	98	94	92
4 by 8 feet	100	100	100	100	96	96	96
4 by 12 feet	96	100	100	100	100	100	100
8 by 8 feet	93	100	100	[2] 97	97	97	97

[1] No losses were replaced after the fourth year. Survivals at 5 years and later are based on the stand which became established the fourth year.

[2] Loss caused by removal rather than by death.

Between the fifth and the tenth year the effect of spacing on height had become apparent (table 1). Ten years after planting, the least average growth was in the block with the closest spacing and the greatest was in that with the widest. After 27 years the growth of trees spaced 8 by 8 feet was approximately 50 percent greater than that of those spaced 4 by 4 feet. It did not greatly exceed that of trees spaced 4 by 12 feet but was appreciably greater than that of those spaced 4 by 8 feet. The difference between spacings of 4 by 4 feet and 4 by 8 feet was evident when the plantings were 15 years old.

Spacing distance affected diameter growth before the plantings were 15 years old; at that time the diameter of trees in the two widest spacings was considerably greater. Little differences occurred between spacings of 4 by 12 feet and 8 by 8 feet throughout the period. The data indicated, however, that future growth is going to be greater in trees spaced 8 by 8 feet. The growth of trees spaced 4 by 4 feet was decidedly less than that of other trees. Figures 1 and 2 show the stem growth of green ash 27 years after planting in row 4 for the spacing distances under discussion.

Crown-spread data were similar to those for diameter growth, the maximum being in trees with the two widest spacings and the minimum in those with the closest one. The growth was sufficient to give approximately complete shade in all spacings except 4 by 12 feet.

Spacing distance had very little influence on survivals, which were good for all spacings.

In recent years each tree in these plantings was classified in a manner patterned after that of Gevorkiantz, Rudolf, and Zehngraff (*8*). Briefly, the information for each tree included crown position in relation to surrounding trees, crown density, soundness, and form. The percentages of trees in each of the various classes 27 years after planting are presented in table 2.

TABLE 2.—*Effects of spacing distance on classification in 1944 of green ash set out in 1918 in mixed plantings*

Spacing distance	Crown position			Crown density			Soundness			Form	
	Above general canopy	In general class	Suppressed	Well-developed	Medium	Poor	No visible injury	Killed back half	Killed to ground	Straight, upright growth	Pushed outward or leaning
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
4 by 4 feet	0	51	49	28	42	30	82	18	0	56	44
4 by 8 feet	0	64	36	45	47	8	98	0	2	78	22
4 by 12 feet	0	90	10	70	26	4	100	0	0	92	8
8 by 8 feet	0	96	4	83	17	0	100	0	0	92	8

The trees showed increasing superiority in crown position and density as the spacing distance was increased, and those with the two widest spacings were best in soundness and form. Of the trees spaced 4 by 4 feet, 49 percent were so badly suppressed that they could be removed without causing any opening in the crown cover. The percentages of trees suppressed and having poorly developed crowns were

FIGURE 1.—Comparison of rows of green ash (indicated by arrows) spaced 4 by 4 feet (*A*) and 4 by 8 feet (*B*), 27 years after being set out in mixed plantings. Note the poorer stem growth of the trees spaced 4 by 4 feet.

FIGURE 2.—Comparison of rows of green ash (indicated by arrows) spaced 4 by 12 feet (*A*) and 8 by 8 feet (*B*), 27 years after being set out in mixed plantings. The stems and tops of trees in both spacing distances were well developed, with the best over-all development in the spacing distance 8 by 8 feet.

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much smaller when spaced 8 by 8 feet than any other distance. A decrease followed each increase in spacing distance.

From this series of plantings it can be concluded that close spacing begins to show effects on height between 5 and 10 years after planting; that a spacing of 4 by 4 feet is detrimental to growth; that greater height and diameter growth were made in 27 years by trees spaced 8 by 8 feet than by those having less distance; and that a higher percentage of these trees were in a vigorous growing condition. The data indicated that these differences will become more pronounced in the future, particularly between trees having a spacing of 4 by 12 feet, or 48 square feet, or more per tree and those having less. Spacing had no appreciable effect on survival, but indications were obtained that trees spaced 4 by 4 feet were beginning to suffer increasing mortality.

Green Ash in Pure Plantings

The growth and survival of green ash set out in pure plantings in 1918 and spaced 4 by 4 and 4 by 8 feet are shown in table 3. Each block was 100 feet long and consisted of 10 rows of trees. The blocks were adjacent and had similar sites and soil types. The wider spaced block required one cultivation early in the season each year to control weeds. The block spaced 4 by 4 feet required no cultivation for many years. No leaf mulch was present in either of the plantings.

Table 3.—*Effect of spacing distance on growth and survival of green ash set out in 1918 in pure plantings*

Spacing distance	Planting of indicated age (years)						
	[1] 4	5	10	15	[2] 20	25	27
	Height						
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
4 by 4 feet	3. 0	5. 2	10. 1	11. 9	8. 5	10. 8	12. 4
4 by 8 feet	3. 0	6. 2	10. 9	13. 8	12. 3	13. 5	15. 2
	Diameter at breast height						
				Inches	*Inches*	*Inches*	*Inches*
4 by 4 feet	------	------	------	1. 6	1. 9	1. 6	1. 8
4 by 8 feet	------	------	------	1. 8	2. 4	2. 4	2. 5
	Crown spread						
							Feet
4 by 4 feet	------	------	------	------	------	------	4. 2
4 by 8 feet	------	------	------	------	------	------	6. 9
	Survival						
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
4 by 4 feet	99	100	98	97	74	72	71
4 by 8 feet	99	100	100	99	92	91	90

[1] No losses were replaced after the fourth year. Survivals at 5 years and later are based on the stand which became established the fourth year.

[2] First measurement period after the severe droughts of 1934 and 1936.

Spacing distance began to affect height growth 5 years after the planting was made; trees spaced wider had grown taller. This trend continued throughout the life of the stand. The severe droughts of 1934 and 1936, when the plantings were between 15 and 20 years old, resulted in heavy killing back of trees spaced closer and less killing back in those with the wider spacing. The block of trees spaced 4 by 8 feet had received considerably more moisture from snowdrifts than that spaced 4 by 4 feet; this may be responsible for part of the differences in killing back.

Diameter growth was greater when the spacing was wider. After 25 and 27 years the diameter was less than after 20 years in the block spaced 4 by 4 feet, because of the heavy killing back previously mentioned. At 25 and 27 years many of the measurements were on second-growth stems, shown by a comparison of the trees in interior rows in figure 3, *A* and *B*.

Crown spread was decidedly better in the block spaced 4 by 8 feet, but 27 years after planting it was not sufficient to give complete coverage between rows.

Losses were greater in the block spaced 4 by 4 feet. They occurred mainly 20 years after planting.

Table 4 shows the classification of the trees in two pure-stand plantings made in 1918. There were no outstanding differences, but the higher percentage of vigorous trees was in the block spaced 4 by 8 feet.

TABLE 4.—*Effect of spacing distance on classification in 1944 of green ash set out in 1918 in pure plantings*

Spacing distance	Crown position			Crown density			Soundness				Form	
	Above general canopy	In general class	Suppressed	Well-developed	Medium	Poor	No visible injury	Killed back half	Killed back three-quarters	Killed to ground	Straight, upright growth	Pushed outward or leaning
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
4 by 4 feet	0	71	29	61	25	14	96	1	0.5	2.5	96	4
4 by 8 feet	0	76	24	67	22	11	96	1	.5	2.5	99	1

The conclusions to be drawn from this series are that greater growth, higher survivals, and more vigorous trees occurred in the block spaced 4 by 8 feet. The data indicate that the differences will become more pronounced as the plantings increase in age. Close planting did not force growth at any period in this series.

Green Ash in Mixed Farm Plantings

Data on the growth and survival of green ash in farm plantings 5, 10, 15, and 20 years old when variously spaced are presented in table 5. The trees were planted during the period 1916–36. Spacing distances were not varied in any one year, but they varied between years, or periods, of planting. Many combinations of species were used in a single year and in different years. The data therefore are not directly comparable, but they show what has happened to a large number of plantings made under the wide range of sites, soil types, climate, and care found on the northern Great Plains.

FIGURE 3.—Comparison of interior rows of green ash (row 6 in each indicated by arrow) spaced 4 by 4 feet (*A*) and 4 by 8 feet (*B*), 27 years after being set out in pure plantings. Note the many second-growth stems of trees spaced 4 by 4 feet.

TABLE 5.—*Effect of spacing distance on growth and survival of green ash planted in farm windbreaks on the northern Great Plains, 1916–36*

Spacing distance	Period planted	Planting of indicated age (years)			
		5	10	15	20
		Height			
		Feet	*Feet*	*Feet*	*Feet*
4 by 8 feet	1916–19	4. 7	9. 2	12. 0	13. 6
6 by 6 feet	1920–21	6. 4	10. 0	11. 6	13. 3
6 by 8 feet	1922	8. 7	10. 8	11. 8	11. 5
6 by 10 feet	1923–26	6. 6	9. 6	11. 8	----
6 by 12 feet	1927–30	5. 5	8. 6	10. 0	----
6 by 15 feet	1931–36	4. 3	8. 5	----	----
		Diameter at breast height			
		Inches	*Inches*	*Inches*	*Inches*
4 by 8 feet	1916–19	----	----	----	2. 4
6 by 6 feet	1920–21	----	----	----	2. 0
6 by 8 feet	1922	----	----	----	2. 2
6 by 10 feet	1923–26	----	----	1. 9	----
6 by 12 feet	1927–30	----	1. 3	2. 0	----
6 by 15 feet	1931–36	0. 6	1. 5	----	----
		Crown spread			
		Feet	*Feet*	*Feet*	*Feet*
4 by 8 feet	1916–19	----	----	----	8. 4
6 by 6 feet	1920–21	----	----	----	6. 1
6 by 8 feet	1922	----	----	----	6. 5
6 by 10 feet	1923–26	----	----	7. 4	----
6 by 12 feet	1927–30	----	6. 1	6. 2	----
6 by 15 feet	1931–36	2. 2	5. 6	----	----
		Survival			
		Percent	*Percent*	*Percent*	*Percent*
4 by 8 feet	1916–19	----	----	72	66
6 by 6 feet	1920–21	----	85	76	60
6 by 8 feet	1922	----	96	68	57
6 by 10 feet	1923–26	91	86	70	----
6 by 12 feet	1927–30	93	74	61	----
6 by 15 feet	1931–36	73	64	----	----

At the ends of the first and second 5-year periods the trees spaced 6 by 8 feet had made the greatest growth and those spaced 6 by 15 feet had made the least. The response of the widely spaced trees may be attributed partly, however, to the fact that more nearly normal rainfall conditions prevailed during the first 5 years of the plantings spaced 6 by 8 feet than during the first 5 years of those spaced 6 by 15 feet. The latter experienced the severe droughts of 1934 and 1936. At the ends of 15 and 20 years trees spaced 4 by 8 feet were tallest. Their increased height may or may not be due to the more or less complete losses of poplar and willow species planted in adjacent or nearby rows, thus giving the green ash increased spacing distances and releasing

many of the trees from suppression. The trees spaced 4 by 8 feet also had the greatest diameters, spread, and survival 20 years after planting.

Crown spread of green ash trees was not sufficient in 20 years to give complete closure when they were spaced 6 by 8 feet. This would indicate that cultivation was required to control weeds in many of these plantings. Observations showed that lack of cultivation resulted in retarded growth.

George (*6*), in a study of Montana farm plantings 15 years old and spaced 6 by 12 feet, found that green ash had greater heights, diameters, and crown spread and higher survivals in plantings free of weeds or sod. Weeds and sod were eliminated by cultivation or overhead shade. Greater growth and higher survivals were found in weedy plantings than in soddy ones. The percentage of winter injury or killing back was highest in the soddy plantings and lowest in the clean ones.

After 5 years of growth 40 to 50 percent of the farm plantings are permitted to grow up to weeds. Under such conditions distances of 10 feet or more between rows are likely to be a detriment to both growth and survival. Weed or sod growth in widely spaced plantings apparently uses more moisture than the additional trees in closely spaced ones. Close spacing tends to check weeds and possibly, as suggested by Ross (*14*), the total leaf area is no greater.

It is of interest to note that 20 years after planting none of the farm plantings, regardless of the spacing distance used, had reached heights which equaled those of the mixed plantings spaced 4 by 8 feet or wider at the Mandan station. They do, however, with one exception exceed those of the plantings spaced 4 by 4 feet.

Diameters of farm plantings were approximately the same as those of the mixed plantings spaced 4 by 8 feet at the Mandan station, but less than those spaced wider.

Comparative crown-spread data of farm and Mandan-station plantings are not available.

Survival data for farm plantings 20 years old are considerably below those of any planting at the Mandan station, regardless of spacing distance. The differences in survival and growth may be attributed to several factors, chief of which are soil type, topography, and care. All of these are favorable at the Mandan station.

Various Deciduous Species in Farm Plantings

Other species of deciduous trees commonly planted on the northern Great Plains may differ considerably from green ash in growth and survival. The growth reached by these species in 15 years might well be used as an index of the distance to be used between rows. Growth and survival data of a few of the species in farm plantings in the past are presented in table 6. They were planted on a wide range of soil types and sites and were subjected to all the climatic conditions found on the northern Great Plains.

Growth data available for some species 20 and 25 years after planting showed little or no increase over those species planted for 15 years. On the average dry, upland site periodic killing back or stagnation of growth took place after the trees had been planted 15 to 25 years.

TABLE 6.—*Average growth and survival that can be expected 15 years after planting various deciduous species in windbreaks spaced 4 by 8, 6 by 6, 6 by 8, 6 by 10, and 6 by 12 feet on the northern Great Plains*

Species	Height	Diameter at breast height	Crown spread	Survival
	Feet	*Inches*	*Feet*	*Percent*
Populus spp.	22. 1	4. 4	13. 3	13
Chinese elm	16. 6	3. 1	13. 0	69
American elm	13. 6	3. 7	8. 7	63
Boxelder	13. 2	2. 3	11. 9	67
Russian-olive	10. 0		9. 6	47
Chokecherry	9. 0		7. 2	73
Siberian pea-tree	7. 7		6. 9	85

GROWTH AND SURVIVAL OF PONDEROSA PINE IN MIXED PLANTINGS

Spacing distance has not been a factor with coniferous species in the early farm plantings, because of the poor stands established even after several years of replanting. Better stands have been established in recent years, but the trees are too young to permit any conclusions on the effect of spacing distance.

In 1918 ponderosa pine was planted in two series of spacings. One series consisted of six-row mixed combinations and the other of five-row ones spaced 2 by 4, 4 by 4, and 4 by 8 feet. Each row was 100 feet long. The arrangement of species in the six-row series was Scotch pine, jack pine, ponderosa pine, Scotch pine, jack pine, and ponderosa pine. That in the five-row series was Black Hills spruce, ponderosa pine, jack pine, Scotch pine, and Black Hills spruce. Cultivation was not practiced in any block in either series after 1923. A heavy needle duff covered the ground in all plantings.

Growth and survival data for the ponderosa pine planted for various periods are presented in table 7. As no further replacements were made after the fourth year, the survival data for the fifth and later years were based upon the fourth-year stand, which might or might not be the actual number of trees planted. Twenty-seven years of growth was completed in the fall of 1944.

In the six-row series heights showed only minor differences 5 years after planting. Spacing distance became a factor after 10 years, the minimum and maximum being in the closest and widest spacings, respectively. This trend continued through the 27 years of growth. A wider difference between spacings of 2 by 4 and 4 by 4 feet and between those of 4 by 4 and 4 by 8 feet occurred each 5-year period. This indicated that spacing was a considerable factor.

Diameter growth showed somewhat similar trends except that after 27 years trees spaced 2 by 4 feet were making greater diameter growth than those spaced 4 by 4 feet. This was brought about by two factors: (1) In row 6 of the block spaced 2 by 4 feet ponderosa pine was located on the edge of a 50-foot strip of cultivated land in contrast with the comparable row in the other block, which was 15 feet away from a Scotch pine row in the next block; (2) the row of adjacent jack pine dropped from a 90-percent survival in 1932 to a 4-percent

TABLE 7.—*Effect of spacing distance on growth and survival of ponderosa pine set out in 1918 in mixed plantings*

Series and spacing distance	Planting of indicated age (years)						
	[1]4	5	10	15	20	25	27
	Height						
6-row series:	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
2 by 4 feet	1. 5	2. 1	7. 1	11. 1	12. 0	13. 6	14. 6
4 by 4 feet	1. 5	2. 1	8. 0	12. 8	14. 5	16. 3	18. 2
4 by 8 feet	1. 5	1. 8	8. 2	14. 6	17. 9	21. 8	23. 9
	Diameter at breast height						
				Inches	*Inches*	*Inches*	*Inches*
2 by 4 feet	------	------	------	1. 3	1. 8	2. 2	2. 6
4 by 4 feet	------	------	------	1. 5	2. 0	2. 3	2. 5
4 by 8 feet	------	------	------	2. 7	3. 4	3. 7	4. 3
	Crown spread						
							Feet
2 by 4 feet	------	------	------	------	------	------	5. 1
4 by 4 feet	------	------	------	------	------	------	4. 6
4 by 8 feet	------	------	------	------	------	------	8. 4
	Survival						
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
2 by 4 feet	99	97	97	84	80	77	77
4 by 4 feet	85	100	98	92	85	83	80
4 by 8 feet	91	100	98	98	96	91	89
	Height						
5-row series:	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
2 by 4 feet	1. 0	2. 1	8. 9	15. 0	18. 9	21. 5	22. 8
4 by 4 feet	1. 5	1. 9	8. 1	13. 6	16. 0	19. 7	22. 3
4 by 8 feet	1. 5	1. 6	7. 5	14. 6	18. 6	23. 1	25. 9
	Diameter at breast height						
				Inches	*Inches*	*Inches*	*Inches*
2 by 4 feet	------	------	------	2. 0	2. 8	3. 4	3. 8
4 by 4 feet	------	------	------	1. 8	2. 7	3. 4	3. 9
4 by 8 feet	------	------	------	2. 6	3. 9	4. 4	5. 2
	Crown spread						
							Feet
2 by 4 feet	------	------	------	------	------	------	6. 3
4 by 4 feet	------	------	------	------	------	------	5. 4
4 by 8 feet	------	------	------	------	------	------	8. 6
	Survival						
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
2 by 4 feet	90	100	100	89	71	69	69
4 by 4 feet	89	100	100	96	83	74	65
4 by 8 feet	89	100	100	100	96	91	91

[1] No losses were replaced after the fourth year. Survivals at 5 years and later are based on the stand which became established the fourth year.

survival in 1935 and to none in 1936, as compared with the 60- and 50-percent survivals in 1935 and 1936, respectively, in the block spaced 4 by 4 feet. These two factors resulted in the ponderosa pine in row 6 of the closest spacing distance having an average diameter of 3.2 inches as compared with 2.8 inches for that in the comparable row in the block spaced 4 by 4 feet. In the block spaced 4 by 8 feet ponderosa pine in the comparable row had an average diameter of 3.9 inches. The average diameters of the ponderosa pine in row 3 were 2, 2.1, and 4.6 inches for the blocks spaced 2 by 4, 4 by 4, and 4 by 8 feet, respectively. The stem growth of ponderosa pine in row 3 of the spacing distances 4 by 4 and 4 by 8 feet is shown in figure 4, *A* and *B*.

Crown-spread data were similar to those for diameter, with the maximum for the widest spacing and the minimum for the middle one (4 by 4 feet). The reasons are discussed under diameter growth.

Losses were not severe, but they showed decreases for each increase in spacing distance.

In the five-row series, which included different competitive species and only one row of ponderosa pine, the heights were somewhat different from those in the six-row series. For the first 20 years the greatest average height was obtained by trees spaced 2 by 4 feet. After 25 years the greatest growth had been made by trees spaced 4 by 8 feet; those spaced 2 by 4 feet, however, were taller than those spaced 4 by 4 feet. The order was the same after 27 years, but the differences were considerably less. Indications were noticed that by the time the trees reach 30 years of age those spaced 4 by 4 feet would exceed in height those spaced 2 by 4 feet. After the plantings were 15 years old the trees in the block spaced 4 by 8 feet were taller than those in the block spaced 4 by 4 feet.

Diameter growth was greatest when spacing was widest (4 by 8 feet). Only minor differences occurred between the two closer spacings. Figure 5 shows the stem growth of ponderosa pine in the spacing distances of 4 by 4 and 4 by 8 feet.

Crown spread was greatest in trees spaced 4 by 8 feet and least in those spaced 4 by 4 feet. The reason for the poorest crown and other growth in the latter is partly explained in the classification of all trees shown in table 8. It will be noted that 40 percent of the trees in the spacing of 4 by 4 feet were suppressed, as compared with 10 and 35 percent in the spacings of 4 by 8 and 2 by 4 feet, respectively.

Losses were much heavier in trees with closer spacings than in those with the widest spacing. This again was caused by the much higher percentage of trees which had been suppressed and consequently were in much weaker condition in the two closer spacing distances.

Reference to table 8 shows that in both series a much higher percentage of trees had their tops in the main crown canopy when they were spaced 4 by 8 feet. These were the ones that made yearly increases in growth and determined the protective value of the planting. A high percentage of the trees were suppressed or had their tops below the main crown canopy in spacings of 2 by 4 and 4 by 4 feet. Many of these trees had made little or no yearly increases in growth for many years and were usually in a weak condition. This is one of the reasons for the poorer growth and survival in the closest distances in both series.

In the five-row series the distance of 4 by 4 feet had a higher percentage of suppressed trees than the distance of 2 by 4 feet. This

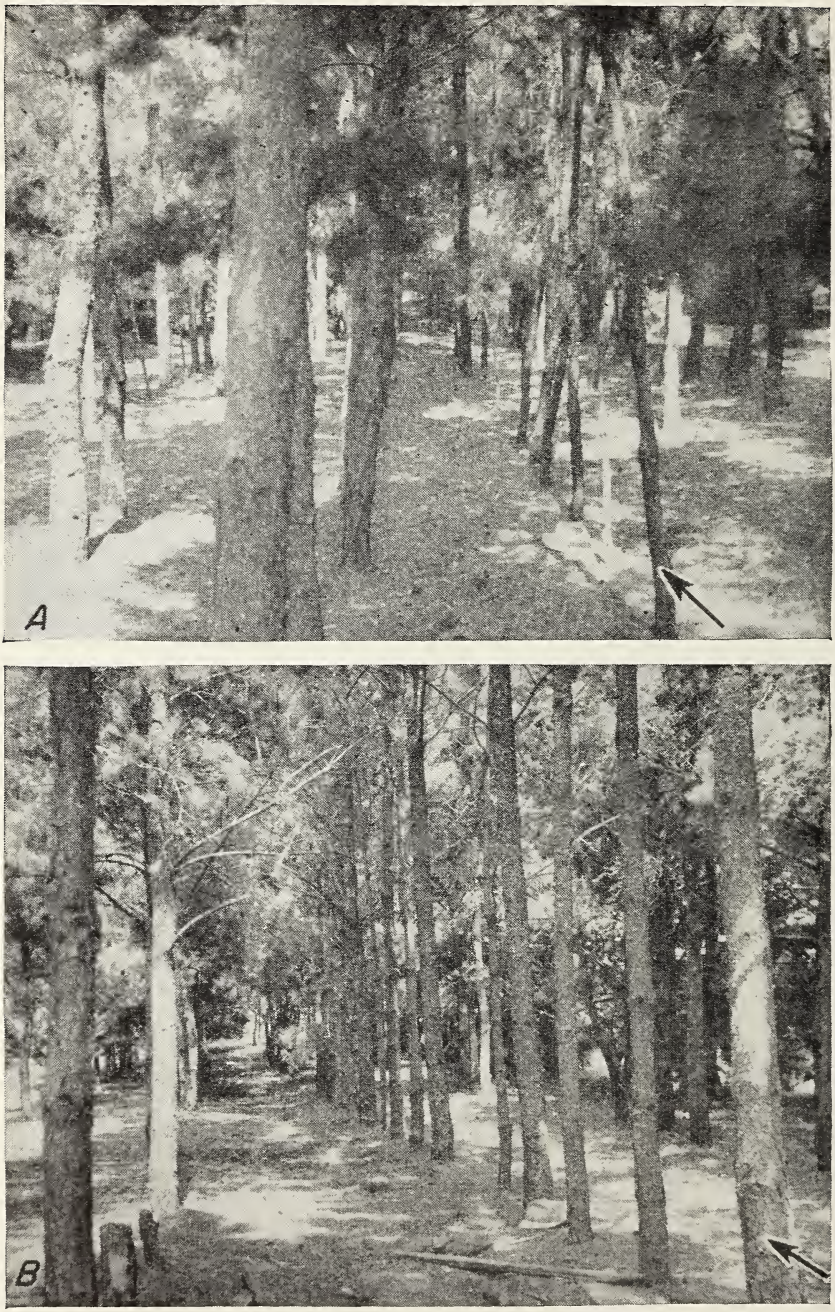

FIGURE 4.—Comparison of ponderosa pines (rows indicated by arrows) in the 6-row series spaced 4 by 4 feet (*A*) and 4 by 8 feet (*B*), 27 years after being set out in mixed plantings. Note the better form and stem growth of trees spaced 4 by 8 feet.

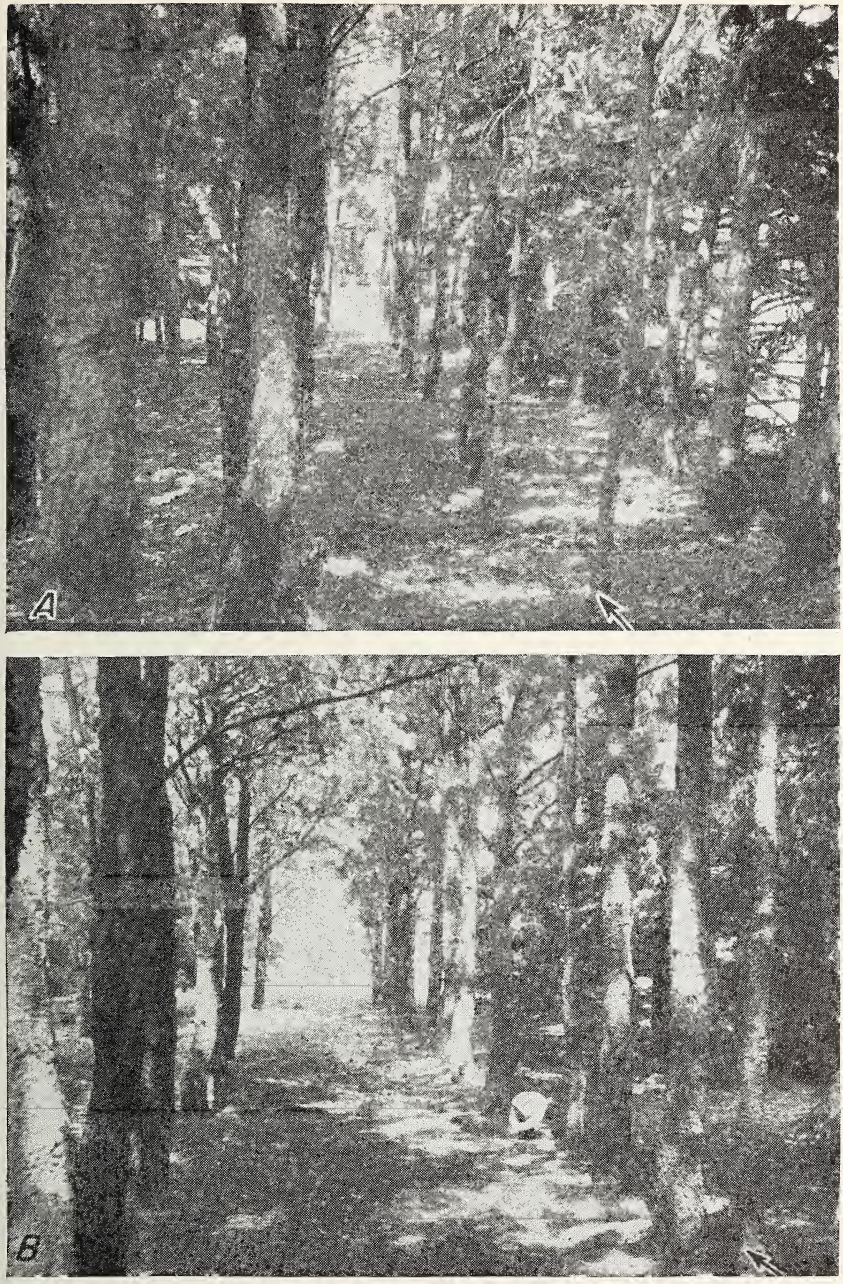

FIGURE 5.—Comparison of ponderosa pines (rows indicated by arrows) in the 5-row series spaced 4 by 4 feet (*A*) and 4 by 8 feet (*B*), 27 years after being set out in mixed plantings. Note the better form and stem growth of trees spaced 4 by 8 feet.

TABLE 8.—*Effect of spacing distances on classification in 1944 of ponderosa pine set out in 1918 in mixed plantings*

Series and spacing distance	Crown position			Crown density			Soundness		Form	
	Above general canopy	In general class	Suppressed	Well-developed	Medium	Poor	No visible injury	Decadent	Straight, upright growth	Pushed outward or leaning
	Per-cent	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*
6-row series:										
2 by 4 feet	0	38	62	24	47	29	100	0	63	37
4 by 4 feet	0	40	60	34	15	51	98	2	71	29
4 by 8 feet	0	67	33	52	27	21	100	0	100	0
5-row series:										
2 by 4 feet	0	65	35	35	39	26	100	0	90	10
4 by 4 feet	0	60	40	60	7	33	100	0	93	7
4 by 8 feet	0	90	10	67	23	10	100	0	95	5

was probably due to the differences in survivals of species in adjacent rows. Black Hills spruce and jack pine survivals were consistently higher in the block spaced 4 by 4 feet than in the block spaced 2 by 4 feet. After 27 years, the jack pine survival in the former block was 48 percent and 18 percent in the latter.

Crown development and tree form of trees spaced 4 by 8 feet were superior to those of closer spacings. The percentage of superior trees decreases with each decrease in spacing distance.

The data presented in tables 7 and 8 show very definitely that a spacing distance of 4 by 8 feet is the minimum necessary for proper growth and survival of ponderosa pine planted in combination with other species.

EFFECT OF THINNING GREEN ASH

Close planting with thinning at a later date has been recommended by several investigators. No data, however, have been presented to show its effects on survival and growth of shelterbelt trees on the northern Great Plains.

The growth and survival of trees in 22 shelterbelt combinations planted in 1915 at the Mandan station were discussed (*5*). A considerable number of trees of certain species were beginning to show heavy losses or were dead in 1934. This dying gave an opportunity to study the growth and survival of green ash thinned by the removal of species in adjacent rows. The average growth and survival in 1933 for four combinations are compared with those for 1944, because 1933 was the year before the first of two severe droughts in 1934 and 1936 (table 9). These combinations were planted on similar sites and soil types. (For these locations see *5*, *fig. 1.*)

Combination 1 was planted to six rows each of birch and green ash, alternated in rows spaced 4 by 4 feet. Heavy losses of birch began early; row 1 was the only having any birch survivals after 1925, and these were dead by the fall of 1934. After that the combination was a pure green ash planting spaced 4 by 8 feet.

TABLE 9.—*Comparison of average growth and survival of green ash in windbreak combinations planted in 1915, when thinned by complete loss of species in adjacent rows and when not so thinned*

Combination	Type of planting	Rows		Spacing distance [1]		Height		Diameter at breast height		Crown spread (1944)	Survival		Remarks
		All species	Green ash	1915	1944	1933	1944	1933	1944		1933	1944	
				Feet	*Feet*	*Feet*	*Feet*	*Inches*	*Inches*	*Feet*	*Percent*	*Percent*	
1	Mixed	12	6	4 by 4 by 4	4 by 8 by 8	19. 6	16. 4	2. 9	2. 7	7. 0	97	72	Became a pure planting spaced 4 by 8 feet in 1934.
3	do	22	4	4 by 4 by 4	4 by 4 by 4 [2]	16. 3	19. 2	1. 8	2. 6	5. 8	96	81	Survivals of adjacent species in 1944 were 80, 92, 80, 88, and 0 percent; the latter became 0 in 1927.
4	Pure	20	4	4 by 4 by 4	4 by 4 by 4 [3]	13. 5	15. 6	2. 0	2. 0	5. 0	93	57	Survivals of adjacent species in 1944 were 76 and 0 percent.
7	Mixed	8	4	4 by 4 by 4	4 by 8 by 8	16. 3	16. 8	2. 2	3. 0	7. 0	99	76	Became a pure planting spaced 4 by 8 feet in 1933.

[1] Distance between trees in the row and between rows on either side.
[2] 1 green ash row had a distance of 36 feet on 1 side.
[3] 1 green ash row had a distance of 20 feet on 1 side.

Combination 3 was planted to 22 rows of trees spaced 4 by 4 feet. Rows 3, 5, 7, and 9 were planted to boxelder and rows 4, 6, 8, and 10 to green ash. Poplar, planted in row 11, became a complete loss in 1927. Boxelder survivals were good throughout the period.

Combination 4 was planted to 20 rows of trees spaced 4 by 4 feet. Siberian pea-tree was planted in rows 1 and 2; green ash in rows 3 to 6; and poplar in the next 4 rows. Siberian pea-tree maintained good survivals. Poplar survivals were very low after 1922, and all trees were dead in 1936.

Combination 7 was planted to 8 rows of trees spaced 4 by 4 feet. Rows 1, 3, 5, and 7 were planted to green ash and rows 2, 4, 6, and 8 to willow. Heavy losses of willow began in 1925, and all trees were dead by the fall of 1933. After that the combination was a pure green ash planting spaced 4 by 8 feet.

Two cultivations a year were necessary to control weeds in combinations spaced 4 by 8 feet in 1944. Those spaced 4 by 4 feet were not cultivated after about 1924; some leaf mulch was present in 1944.

Removal of alternate rows of trees had no beneficial effect on growth or survival of green ash in combinations 1 and 7 as compared with those of nonthinned trees in combination 3 and with the height growth of nonthinned trees in combination 4. The thinned trees suffered more severe drought injury in 1934 and 1936 than did the trees in combination 3. In combination 4 the two rows of green ash nearest the Siberian pea-tree suffered heavy killing back after the droughts, and many of the diameter measurements in 1944 were of second-growth stems. This resulted in no increase in diameter between 1933 and 1944. If the two most important factors essential in a windbreak (height growth and survival) are considered, then the removal of alternate rows in original spacing distances of 4 by 4 feet may prove more detrimental than beneficial to the surviving trees over a period of 30 years.

Table 10 presents additional data on the effects of thinning green ash in combinations planted on similar sites and soil types. Sufficient cultivation was done to control weeds. None was needed after about 1924 in combinations spaced 4 by 4 feet; leaf mulch was present in 1944. Some cultivation was required in combinations spaced wider. Because of heavy losses of species in adjacent rows the green ash in combinations 17, 18, and 22 had additional spacing after 1933. At that time the trees with the wider spacings were best. The complete removal of the rows on one side of the green ash and the partial removal of those on the other did not increase the height and survival, but crown spread was more in combinations 17 and 18 than in 16.

EFFECT OF ADJACENT SPECIES ON SPACING NEEDED FOR GREEN ASH

It has been previously pointed out (*5* and p. 14) that the selection of a spacing distance might well be based on the growth habits of the species making up the planting. Data on the behavior of green ash when planted adjacent to various other species at several spacing distances are available from the series of combinations previously mentioned (p. 20). These data showing the growth and survival of green ash in 1933 and 1944 are presented in table 11.

TABLE 10.—*Comparison of average growth and survival of single rows of green ash when thinned by loss of species in adjacent rows and when not thinned*

Combination	Rows of all species	Year of planting	Spacing distance [1]		Height		Diameter at breast height		Crown spread (1944)	Survival		Remarks
			Original	1944	1933	1944	1933	1944		1933	1944	
			Feet	*Feet*	*Feet*	*Feet*	*Inches*	*Inches*	*Feet*	*Percent*	*Percent*	
16	9	1916	4 by 4 by 4	4 by 4 by 4	10. 5	17. 9	0. 8	2. 3	6. 0	100	100	Adjacent species had survivals of 100 and 92 percent in 1933 and 64 and 68 percent in 1944.
17	4	1916	4 by 4 by 4	4 by 4 by 20	11. 7	17. 8	1. 2	2. 5	8. 0	96	96	Adjacent species on one side died in 1926. The other side had survivals of 92 percent in 1933, 32 percent in 1937, and 16 percent in 1944.
18	6	1917	6 by 12 by 12	6 by 12 by 32	17. 4	18. 1	2. 1	2. 7	8. 0	100	94	Adjacent species had survivals of 94 percent in 1933, 23 and 88 percent in 1935, 12 and 76 percent in 1936, and 12 and 59 percent in 1944.
22	10	1917	4 by 8 by 8	4 by 8 by 16	18. 2	15. 9	2. 3	3. 2	6. 0	88	76	Adjacent species had survivals of 0 and 92 percent in 1933, 0 and 36 percent in 1935, and 0 and 24 percent from 1939 through 1944.

[1] Distance between trees in the row and between rows on either side.

Green ash planted between rows of boxelder and spaced 4 by 4 feet made good height and diameter growth in all combinations. Crown spread was not as good as when the green ash was planted between some other species. Stands of adjacent boxelder remained good throughout the period. The green ash suffered more suppression in two adjacent rows than in single ones alternated between rows of boxelder.

Each combination of green ash planted between boxelder and poplar or willow species had additional space after 1933 because of the loss of adjacent poplar or willow species. Despite the increased space the green ash had not benefited to any appreciable extent. Height growth was seriously affected by suppression in the spacing of 2 by 8 feet; this was caused by the close spacing in the row rather than by the species in adjacent rows.

Adjacent willow and willow or birch and birch were dead after 1933 and 1934. In combination 1 the birch started dying before they had become much of a competitive factor. In 1933 the green ash trees in this combination were 3.3 feet taller than those in combination 7, planted to alternate rows of willow and green ash species. In 1944 the greater height, diameter, and survival were in combination 7, which had become a pure green ash planting, spaced 4 by 8 feet, in 1933. The willow had been more competitive than the birch previous to that time. Green ash in combinations 1 and 7 suffered very heavy killing back during the drought years. Despite the increase of spacing distance from 4 by 4 feet to 4 by 8 feet during the 10 to 18 years prior to 1944, the trees in combination 7 made only a small increase in growth from 1933 to 1944. Those in combination 1 killed back to an extent that made them over 3 feet shorter in 1944 than they were in 1933. Heavy losses in stand occurred in both combinations.

Adjacent Siberian pea-tree had a decidedly unfavorable effect on both growth and survival of green ash. This occurred despite the fact that most of the adjacent poplar on the other side had been dead for 23 years. Four rows of green ash were planted between Siberian pea-tree and poplar in combination 4. In 1944 the averages for each of the four rows in order from Siberian pea-tree to poplar were 14.5, 15.5, 16.2, 16.3 feet in height and 44-, 56-, 68-, and 60-percent survivals. Poplar species in the adjacent row had a 12-percent survival in 1922 and a 4-percent one in 1925. The increased spacing for the green ash row adjacent to the poplar had but little beneficial effect on growth or survival when compared with that of the next interior row.

Combination 6 had four rows of green ash alternated with boxelder rows. Siberian pea-tree was on one side of one green ash row. The close spacing between trees in the row had very unfavorable effects on growth and survival; 63 percent of the trees were suppressed as a result of overtopping by trees within the row. The row of green ash trees adjacent to Siberian pea-tree had an average height of 10.8 feet and a survival of 68 percent, as compared with averages of 13.9, 14, and 12.6 feet in height and 86-, 74-, and 82-percent survivals for the other three rows, all of which were adjacent to boxelder.

Green ash was planted between boxelder and Chinese elm with three spacing distances. The Chinese elm had a very depressing effect on growth of green ash in plantings spaced 4 or 8 feet between rows. Suppression of the green ash by Chinese elm was very heavy in 4-foot rows, 87 percent of the trees being suppressed. Severe killing back

TABLE 11.—*Effect of species in adjacent rows on average growth and survival of green ash in windbreak combinations*

Combination	Species adjacent [1]	Sets of green ash rows in combination	Green ash rows in each set	Year of planting	Spacing distance [2]		Height		Diameter at breast height		Crown spread (1944)	Survival		Green ash suppressed in 1944
					Original	1944	1933	1944	1933	1944		1933	1944	
		Number	*Number*		*Feet*	*Feet*	*Feet*	*Feet*	*Inches*	*Inches*	*Feet*	*Percent*	*Percent*	*Percent*
3	Boxelder	4	1	1915	4 by 4 by 4	4 by 4 by 4–36 [3]	16.3	19.2	1.8	2.6	5.8	96	81	31
16	Boxelder	1	1	1916	4 by 4 by 4	4 by 4 by 4	10.5	17.9	.8	2.3	6.0	100	100	20
15	Boxelder	1	2	1916	4 by 4 by 4	4 by 4 by 4	13.0	17.1	1.2	2.2	5.0	98	98	35
2	Boxelder on one side; poplar or willow on other	1	2	1915	4 by 4 by 4	4 by 4 by 4–12 [4]	17.7	17.8	2.1	3.0	6.5	100	78	29
17	Boxelder on one side; poplar or willow on other	1	1	1916	4 by 4 by 4	4 by 4 by 20	11.7	17.8	1.2	2.5	8.0	96	96	17
5	Boxelder on one side; poplar or willow on other	1	2	1915	2 by 8 by 8	2 by 8 by 8–24 [5]	15.6	13.9	1.7	2.2	7.5	94	71	54
7	Willow on both or birch on both.	4	1	1915	4 by 4 by 4	4 by 8 by 8	16.3	16.8	2.2	3.0	7.0	99	76	21
1	Willow on both or birch on both.	6	1	1915	4 by 4 by 4	4 by 8 by 8	19.6	16.4	2.9	2.7	7.0	97	72	42
4	Siberian pea-tree on one side; poplar on other	1	4	1915	4 by 4 by 4	4 by 4 by 4–20 [6]	13.5	15.6	2.0	2.0	5.0	93	57	23
6	Siberian pea-tree or boxelder on one side; boxelder on other	4	1	1915	2 by 8 by 8	2 by 8 by 8	12.1	12 8	1.2	1.7	4.8	95	78	63
18	Boxelder on one side; Chinese elm on other	1	1	1917	6 by 12 by 12	6 by 12 by 32	17.4	18.1	2.1	2.7	8.0	100	94	25
22	Boxelder on one side; Chinese elm on other	1	1	1917	4 by 8 by 8	4 by 8 by 16	18.2	15.9	2.3	3.2	6.0	88	76	32
19	Boxelder on one side; Chinese elm on other	1	1	1917	4 by 4 by 4	4 by 4 by 4	10.7	14.0	.9	2.0	5.0	96	92	87

[1] All poplar, willow, and birch species were either dead or had very low survivals in the fall of 1933.
[2] Distance between trees in row and between rows on either side.
[3] 1 row of green ash had a distance of 36 feet on 1 side.
[4] 1 row of green ash had a distance of 12 feet on 1 side.
[5] 1 row of green ash had a distance of 24 feet on 1 side.
[6] 1 row of green ash had a distance of 20 feet on 1 side.

of trees took place in the two wider spacings; despite the increased space they made less growth in height and diameter between 1933 and 1944 than did the trees in the closest spacing, which remained the original 4 by 4 feet through 1944. These data show that Siberian pea-tree and Chinese elm will become highly competitive species to green ash when planted in rows 4 and 8 feet away. When Chinese elm is the competitive species, green ash will make better growth when planted in rows 12 feet away.

EFFECTS OF WIDE SPACING ON WINTER INJURY OF DECIDUOUS SPECIES

The data in table 11 show that in some cases the average height of trees in 1944 was less than that in 1933 or was little changed. Killing back at some intervening period was the reason. All the trees received the same amounts of precipitation, and cultivation was practiced when needed to control weeds. In 1933 green ash in combinations 7, 1, 18, and 22, spaced 4 by 8 feet or wider, had average growths which were better than those of trees which were spaced 2 by 8 and 4 by 4 feet. These differences were reversed in some plantings in 1944. The trees in the wider spacing distances were better developed in 1933 but suffered greater injury after the severe droughts and made slower recovery than the less developed trees in the closer spacings. The latter all showed growth increases between 1933 and 1944 except one planting spaced 2 by 8 feet. Apparently the limited moisture was insufficient to take care of the demands of the larger, well-developed trees, whereas the less developed ones having less leaf area per tree were able to survive the more limited demands of transpiration and evaporation. This may be a factor of considerable importance because periodic severe droughts are reasonably certain to occur on the northern Great Plains. It also agrees with the findings of Scholz (*15*), previously referred to.

Green ash is a species which matures its wood and sets its terminal bud early in the fall each year. In very dry seasons the species goes into a more or less dormant condition early in the summer. Other species of an indeterminate habit of growth continue growth until stopped by killing frosts and are more easily injured by fall freezes. There are some indications that the spacing distance of such trees may be a factor in determining the amount of injury or loss suffered in wet falls.

During the growing season, May to September 1942, the precipitation at the Mandan station was 11.47 inches as compared with 10.58 inches, the 30-year average for the same months. August and September rainfall that year was 3.63 inches as compared with the 30-year average of 2.78 inches. In a series of spacing experiments (5 by 10, 10 by 10, 10 by 15, and 15 by 15 feet) 3-year-old Chinese elms in all spacing distances were killed to the ground or dead in the spring of 1943. The injury was observed in early April, when the wood was dry and brittle. An unusually early severe freeze occurred late in September 1942, when the elms were in a vigorous growing condition. The number of trees actually dead was considerably greater in the widest distance (15 by 15 feet) than in the closest distance (5 by 10 feet). Soil-moisture studies in the fall of 1942 on both sides of the Chinese elm rows indicated that a greater percentage of available moisture was present in the widest distance.

Injury and loss to Chinese elms at that time were described by George (7) as being widespread over the northern Great Plains. Observations made by him and others tended to show that the injury and loss were much less severe in closely spaced plantings or in those having a heavy weed or sod growth. It is reported that G. D. Matthews, in discussing the winter injury of 1942–43 at Scott, Canada, stated: "Due to labor shortages they were unable to keep weeds down and as a result had less winter injury in 1942–43 than those who had clean cultivation." [2]

During the growing season of 1943 at Mandan there was 3.14 inches above the average amount of precipitation for the 30-year period. August and September rainfall was 0.58 inch above the average. Freezing temperatures which would check the growth of indeterminate species such as Russian-olive did not occur until the last of October. In the spring of 1944 the Russian-olive was found to have suffered heavy killing back or complete loss in the series of spacing experiments previously described for the Chinese elm. This killing unquestionably occurred in the fall rather than the winter months. Losses in the blocks spaced 5 by 10, 10 by 10, 10 by 15, and 15 by 15 feet were 0, 10, 10, and 83 percent, respectively. The percentages of surviving trees which killed back, in the same order of spacing distances, were 25, 71, 50, and 100 percent.

Soil-moisture studies made in the fall of 1943 on both sides of the Russian-olive rows showed the least amount of available moisture in the block spaced 5 by 10 feet and the greatest amount in that spaced 15 by 15 feet. Severe killing back and loss of Chinese elm and Russian-olive over a wide area, such as occurred in the falls or winters of 1942–43 and 1943–44, are not common on the northern Great Plains. A somewhat similar killing of Chinese elms occurred in the central Great Plains after a severe sudden drop in temperature in the fall of 1940. The soil was unusually wet in the falls of 1942 and 1943 as contrasted with the generally dry condition of land supporting tree growth.

These data are by no means conclusive that tree species of indeterminate habits of growth in wide spacing distances are going to suffer greater injury and loss in years of plentiful soil moisture than are like species planted in closer distances; nor are they conclusive that earlier maturing species, such as green ash, in wide spacing distances, are going to suffer greater injury and make slower recovery after severe drought years than similar species in closer spacing distances. The data do, however, show certain trends in this direction and point the way for further study.

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